High Frequency Acoustical Propagation and Scattering in Coastal Waters

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LONG-TERM GOALS

To study the physical processes controlling the propagation of high frequency acoustical signals. Of particular interest is the relationship between bubble distributions, surface gravity waves and turbulence and their effects on sound propagation as it affects underwater communication. A second long-term goal is to model these processes to improve our understanding and to enhance the predictive capabilities.

OBJECTIVES

Our objectives are (1) to develop new techniques and approaches for high frequency acoustical propagation experiments in environments with dense bubble distributions and significant turbulence; (2) to carry out such experiments; (3) to model sound propagation in these environments; and (4) to interpret the results in terms of appropriate acoustic models.

APPROACH

Our approach to studies of high frequency propagation in bubbly water near the ocean surface includes observational and model analysis of forward and back-scattered sound as well as analysis of the naturally occurring ambient noise field.

A preliminary attempt to acquire data during the Martha's Vineyard Coastal Observatory experiment (SPACE02) was foiled by a failed mooring and loss of instruments. A revised experiment will be carried out in Narragansett Bay using rebuilt equipment. The new instrumentation includes high-frequency (100kHz) acoustical backscatter in both vertical and slant mode operation investigate dense bubble clouds in the surf zone and their link to wave and bottom induced turbulence. In addition the acoustic system is being set up on a bistatic array so as to permit transmission of communication signals at the same time as surface and volume back scatter measurements are being acquired. Bubble populations inferred from the sonars can be verified with *in situ* sensors (i.e. Farmer Booth & Vagle,

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1998 and 2005) and have proven effective at measuring the acoustical environment in inshore waters (Vagle, Farmer & Deane, 2001).

Key individuals involved in the work:

- D M Farmer is an acoustical oceanographer responsible for project design and analysis.
- S Vagle is an acoustical oceanographer responsible for implementation of acoustical systems, experimental execution and data analysis.
- G Deane is an acoustical oceanographer at Scripps who is collaborating in the research including both field studies and acoustic analysis
- J Preisig is a researcher from Woods Hole who is collaborating in both field studies and data analysis and interpretation.
- A Lavery is a researcher at Woods Hole who is interested in working with us on high frequency propagation and turbulence.

WORK COMPLETED

The result of the accident the MVCO experiment (SPACE02), namely to obtain environmental measurements at the specular points of J. Preisig's acoustical arrays, was not met. Based on the experiences from this effort we have developed a new experimental plan and have rebuilt the instrumentation. This plan is less complex while ensuring that we obtain the essential bubble measurements relevant to interpretation of propagation effects on the communication path to be used by Jim Preisig..

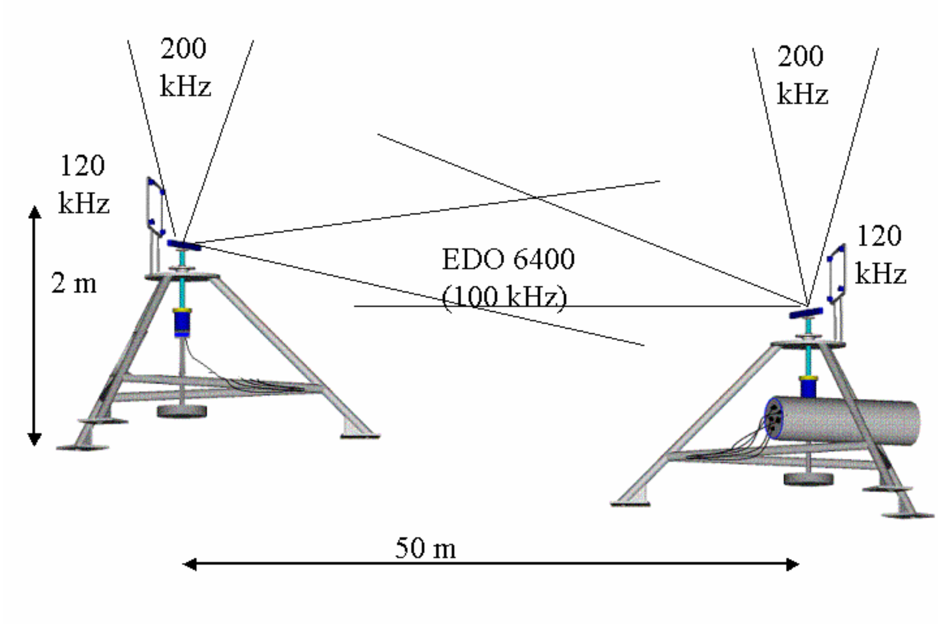

Figure 1. Diagram showing new instrumentation constructed for backscatter and propagation measurements in Narragansett Bay. Sonars are mounted on two tripods deployed approximately 50m apart.

RESULTS

The instrumentation has now been built and deployed in Narragansett Bay and an extensive data set acquired. This includes horizontal propagation, back scatter Doppler sonar measurements from the surface and with azimuthally swept beams, video and other supporting data. A schematic showing the basic instrumentation for back scatter and propagation measurements is given in Figure 1.

Figure 2 shows raw signals from the horizontal propagation path. Direct path, bottom path and surface returns are shown for both reciprocal transmissions. The signal transmission is flexible and can be programmed for a wide variety of pulse forms. We are currently working with m-sequences.

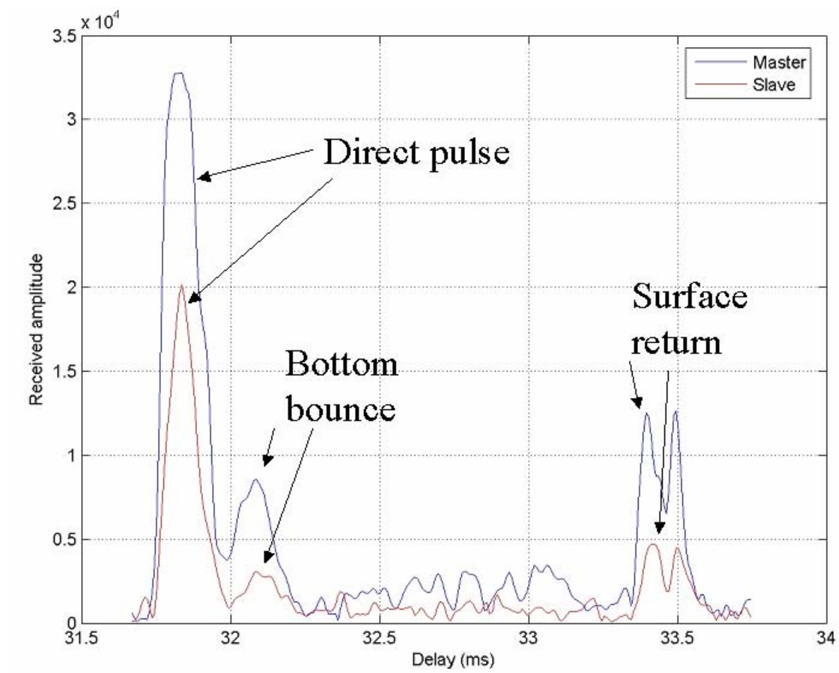

Figure 2. Sample pulses received from the reciprocal transmission paths showing direct, bottom bounce and surface returns in each direction.

The reciprocal horizontal propagation transmissions have now been run for extended periods and reveal variability associated with changing sound speed and along path component of the flow speed. The signal is phase coherent allowing high time resolution. Figure 3 shows 12 hours of propagation measurements where the tidal modulation is clearly apparent in travel time associated with the direct path and surface scatter.

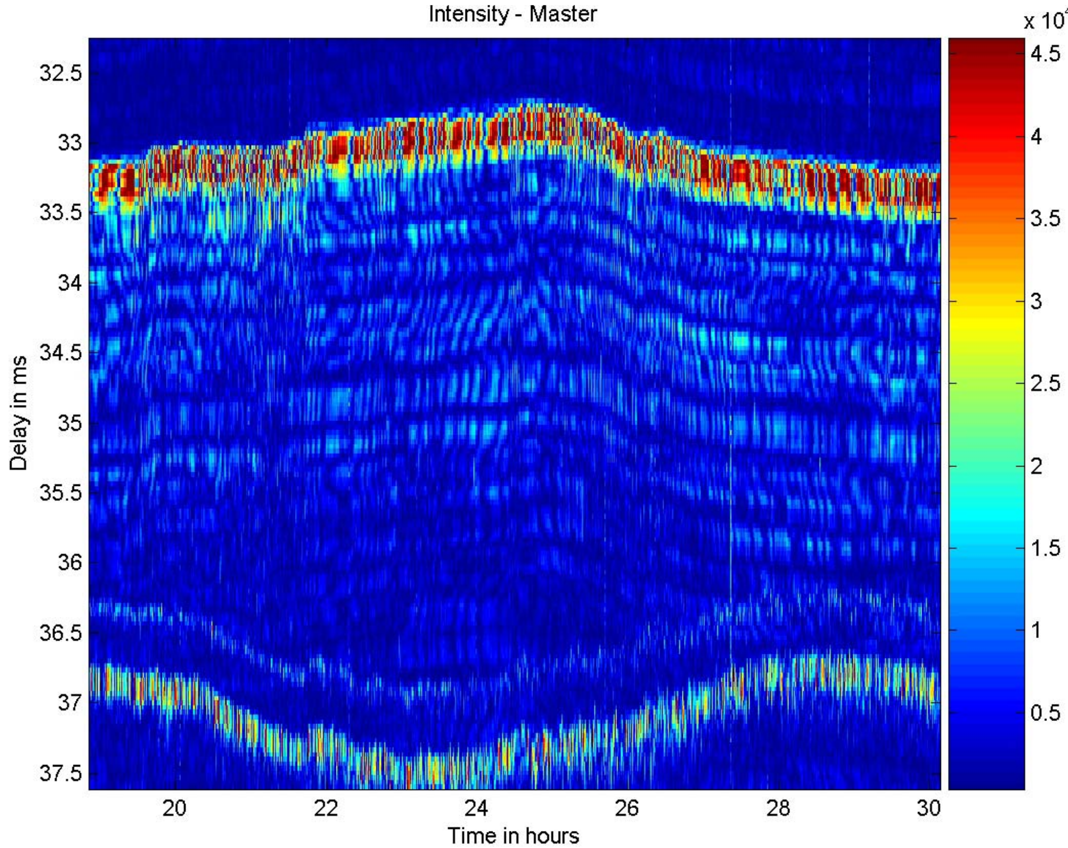

Figure 3. Color image of horizontal propagation arrival time and intensity for 12 hours of data in Narragansett Bay. The heavy red line at the top shows the direct path, which is influenced by currents and sound speed, and the lighter line at bottom shows surface scatter which is modulated primarily by tidal elevation.

The system also include horizontally imaging azimuthally narrow Doppler sonars that are motor driven to generate polar images, in addition to two 200kHz vertical sonars. Figure 4 shows short representative data segments acquired with these sonars. The vertical sonars can image bubble clouds and the surface waves directly above the transducer. The horizontally rotating sonars image the horizontal distribution of bubbles and their organization by Langmuir circulation, as well as providing Doppler information for recovering the directional wave field. Heading pitch and roll are also measured.

All the data are transmitted by cable to shore where they can be stored, and are also available as data streams over the internet. Our current effort is focused on correcting some software errors in the control, and gaining experience in the signal processing.

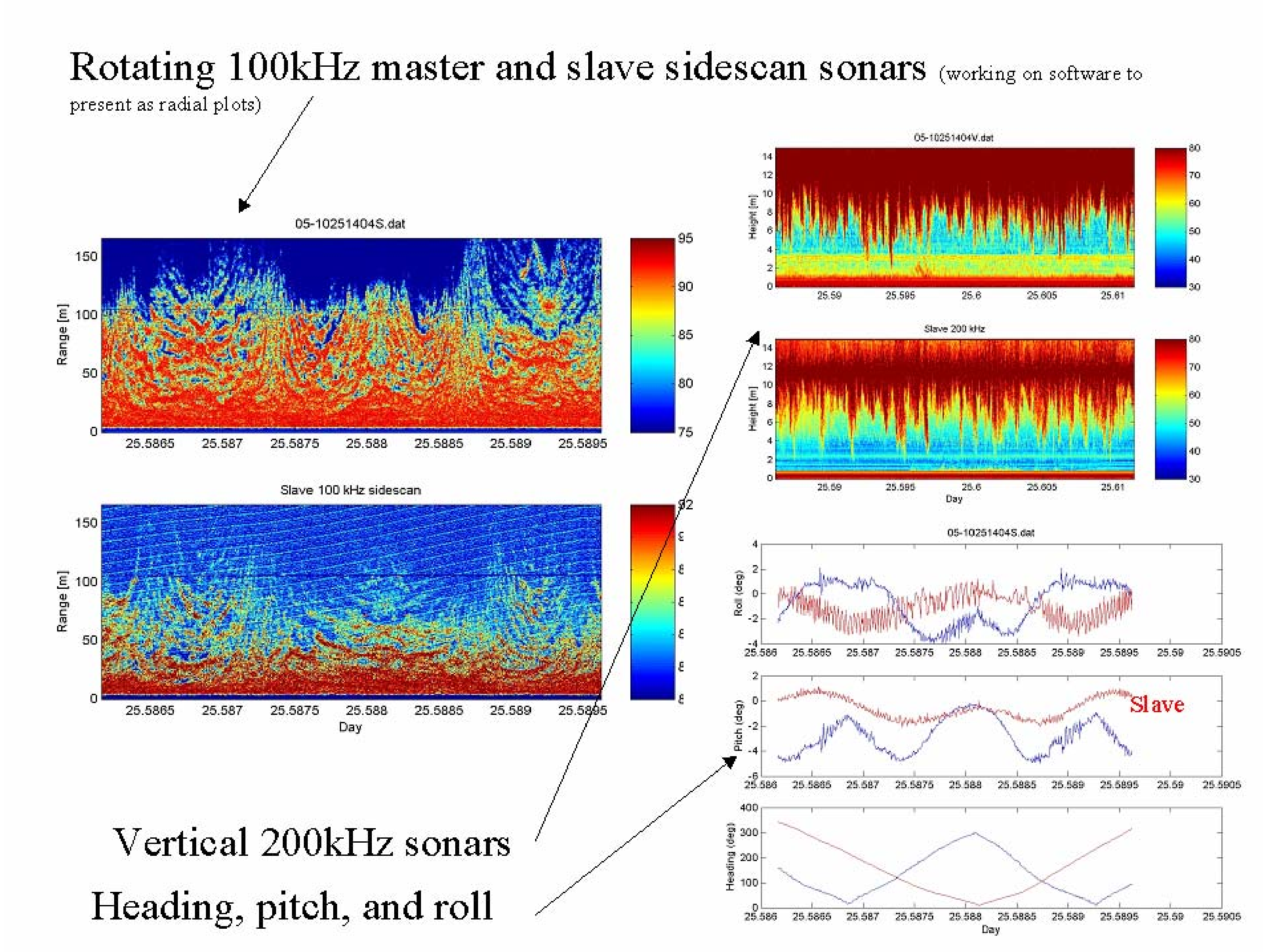

Figure 4. Sample images from the bottom mounted bistatic sonar system inNarragansett Bay showing horizontally imaged back scatter from the azimuthally rotating narrow beam sonars (left), and vertical imaging of bubble clouds at the same time, with the 200kHz vertical sonars. Vertical sonars measure waves and verticalpenetration of bubble clouds, horizontal sonars acquire images of the horizontal organization of bubbles and Dopple data for wave field analysis. Lower left: Heading, pitch and roll of the motor driven sonars.

IMPACT/APPLICATIONS

Considerations of the hydrodynamic impacts of the surface wave field, the bubbles and the turbulence are critical to the development of robust acoustical propagation models (Vagle, Farmer & Deane, 2001; Farmer, Deane & Vagle, 2001). The present studies and modeling efforts, combined with a revised experiment will improve our understanding of significant problems associated with sound propagation in the presence of bubbles and turbulence, especially as it applied to underwater acoustic communication. Analysis of the resonator performance, taking due account of reverberation effects, will provide added confidence in the use of this instrument in bubble measurements.

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PUBLICATIONS

Farmer, David M., Svein Vagle & Donald Booth, Reverberation effects in acoustical resonators used for bubble measurements, *J. Acous. Soc. Amer.,* 118(5), Nov, 2005.

HONORS/AWARDS/PRIZES

Elected Fellow of the Royal Society of London. (D Farmer, University of Rhode Island.)